System and Apparatus for Vehicle Electrical Power Analysis

Field of the Invention

The present invention relates to a vehicle electrical power system and apparatus and refers particularly throughout exclusively to a system and apparatus for monitoring, analysing, testing and reporting on the condition of a vehicle electrical power system.

Background to the Invention

Modern automobiles have a high level of electronic equipment. As a result the reliability of electrical power supply of a vehicle is important. The inability to detect problems, and provide an early warning of problems, extracts from the reliability of the vehicle electrical power system.

Many types of secondary storage batteries are used in the vehicle industry such as, for example, lead acid battery, nickel-cadmium battery, silver cadmium battery, and others. The most popularly used in the vehicle industry is the lead-acid battery.

Chemical storage batteries, such as lead acid batteries used in automobiles, have existed for nearly a century with much improvement in reliability. However, due to the critical working environment of the battery such as, for example wide range of operating temperatures and high cranking currents, battery power failure is still unpredictable and may at times be without warning.

A vehicle electrical power system consists of a battery, an alternator, and loads. The loads include the starter motor. The battery is the key component of the vehicle electrical power system. The battery is mainly for starting, lighting and ignition. The battery receives energy from the alternator, and supplies energy to the starter motor and other loads. Any defective element in the power system will cause system failure.

Presently, various techniques are used to determine battery status. For example, one may use the measurement of the specific gravity of the electrolyte, the

measurement of open circuit voltage; the measurement of internal resistance, conductance, capacity, and cranking current, by using AC or DC source or load. A more popular method uses a load tester (Hundreds-Ampere-Second discharge) to test the battery with a high current discharge for a few seconds. It monitors voltage changes to determine battery status.

However, these tests are not the actual load on the battery under operating conditions. They are only indicative of battery status. They only indicate the condition of the battery with an open circuit and without load or charging current. This means that such testing is under "off line" conditions that provide only static data. Hence, these methods do not provide an accurate, dynamic measurement when there is interference by charging current, load current, ripple noise, and other noises, which exist in an actual operating environment.

Cranking Ampere ("CA") or Cool Cranking Ampere ("CCA") and State of Charge ("SOC") are important parameters of a battery. The cranking current capacity or cranking current percentage of a battery can only be determined by comparing the measured data with the manufacturer's reference data. A positive determination given by a CA or CCA test may not be correct if the battery is undersized for a particular application. The SOC indicates the charge percentage status of a battery. However, if the capacity of the battery is degraded, the SOC cannot used to determine the actual capacity of the battery.

Summary of the Invention

In one aspect of the invention there is provided a microprocessor directly coupled with an input controller and an output controller. The input controller consists of an analogue-to-digital converter, and a voltage gradient detector. The terminal voltage of a battery being monitored is adapted to a pre-scale network filter and coupled to the analogue-to-digital converter.

The terminal voltage of the battery is compared with a reference voltage. The voltage signal is converted to digital form, and then input to microprocessor through a data bus. The voltage gradient detector detects the input waveform and provides the gradient status of the voltage signal, and input to the microprocessor. The input data analyser and sequencer of the microprocessor process the data

and provide the sequence-gating signal to control the analogue-to-digital converter, and perform data measurement.

The microprocessor executes its program in a memory consisting of ROM (read only memory), and EEROM (electrical erasable read only memory). The microprocessor also stores measurement data in the EEROM thereby using it as a database.

The data analyser performs information processing and outputs to the output controller. It provides message, test data, and warning signals if the data is outside the set limit.

The output controller consists of a digital-to-analogue converter, message generator, message display, tone generator, tone and speaker, colour pattern generator, full colour LED, infrared printing interface, infrared transmitter, computer communication interface, and communication port. A keypad is coupled with the microprocessor for controlling inputs. A timer provides time reference to microprocessor.

The present invention is particularly applicable to the monitoring of a terminal transient response voltage waveform and using that waveform to analyse the electrical power system of the vehicle under various working conditions. At the same time it can determine the cranking circuit quality, cranking torque capability, battery and starter cranking power capability, and alternator working status, to provide comprehensive information of the engine operational status.

It may be installed in a vehicle for on line measurement, a working station, or hand-held portable system, for industrial or professional application.

Brief Description of the Drawing

In order that the present invention may be readily understood and put into practical effect, there shall now be described by way of non-limitative example only a preferred embodiment of the present invention, the description being with reference to the accompanying illustrative drawings in which:

Figure 1 is a block diagram of an embodiment for a vehicle electrical power system under test;

Figure 2 is an illustration of an equivalent closed circuit of the vehicle electrical power system;

Figure 2A is an illustration of an ignition pulse and ripple waveform;

Figure 2B is an illustration of an alternator ripple waveform;

Figure 2C is an illustration of an ignition pulse waveform;

Figure 3 is an illustration of a signal flow input controller to microprocessor;

Figure 4 is an illustration of a signal flow output controller to output driver;

Figure 5 is a flowchart of a first part;

Figure 6 is a flowchart of a second part;

Figure 7 is a flowchart of a third part;

Figure 8 is a flowchart of cranking torque capability and circuit quality;

Figure 9 is a flowchart of cranking power capability and engine cranking ability;

Figure 10 is a flowchart of alternator charging performance; and

Figure 11 is a flowchart of remnant operating time.

Preferred Embodiment

The embodiment illustrated in Figure 1 shows an apparatus (150) for monitoring, testing, analysing and the reporting of a vehicle's electrical power system. It is particularly applicable for measuring the terminal transient response voltage waveform and using that waveform to analyse the electrical power system of the vehicle at a number of different engine status conditions, including resting, cranking, and running. The apparatus (150) is able to evaluate the cranking circuit quality, cranking torque capability, battery-starter cranking power capability, and alternator charging condition. It can also provide a comprehensive report.

Referring first to Figure1, the vehicle electrical power system (100) consists of starter (101), internal combustion engine (105), generator or alternator (106), cranking switch (107), ignition switch (108), loads (109), and battery (110).

The internal combustion engine (105) is the main energy provider. It converts chemical energy to mechanical energy and heat. The chemical source may be gasoline, diesel, or other fuels. The internal combustion engine (105) cannot be started without an initial cranking power. The battery (110) provides power for the control system, and ignition energy for the engine once the ignition is turned on. It

combines with the starter (101) to provide the initial cranking power to crank the internal combustion engine (105).

The engine (105) drives the generator or alternator (106), which converts the mechanical energy to electrical energy. The generator/alternator (106) may be a 3-phase star-connected full-wave rectifier, with a multi-pole built-in voltage regulator, and temperature compensated electro-mechanical device. The working speed of the alternator (106) is from 1,000rpm to 10,000rpm. Normally the rated-power output speed is around 5000rpm. The function of the regulator is to control the output to obtain relatively constant voltage under a wide range of operating speeds and under various loads. The alternator (106) provides sufficient energy required by loads (109), and additional energy to charge the battery (110), under normal operation.

Alternator and battery performance

The frequency of the ripple generated by the alternator (106) can be determined as:

$F_r=6*P*M*S_e/60$ or $F_r=6*P*M*n$

where P= number of pair of poles

M= mechanical coupling ratio of engine to alternator (106)

S_e= rotation speed of the engine (105) in rpm

n= rotation speed of the engine (105) in rps

For example, for a 6-pole alternator (106), having 3 pairs of poles, an engine (105) running speed range from 800rpm to 6000rpm, and M=1.5, the ripple frequency range is determined as:

F_r=240Hz to 2700Hz

When any diode of a 3-phase bridge rectifier malfunctions, or any phase circuit is opened, the alternator will work as a single-phase output device. The ripple frequency then becomes:

$F_r=2*P*M*S_e/60$

The Fr range becomes

Fr=80Hz to 900Hz

The speed ratio N_a of the alternator and the engine is derived as follows:

$S_a=M*S_e$, then

$N_a=S_a/S_e=M$

Normally, the speed ratio N_a of alternator (106) and engine (105), S_a/S_e, and, the ratio of ripple frequency and ignition pulse frequency F_r/F_I, are constant. For a faulty alternator with one phase malfunctioning, the ripple frequency will only achieve 1/3 that of a normal alternator. A loose driving belt may change the speed ratio, or frequency ratio, due to drive belt slip. The change of speed ratio and frequency ratio can determine the condition of the alternator.

The ripple factor R_f of the ripple voltage is derived as follows:

$$R_f = (V_{rr} / V_{ave})*100\%$$

where V_{rr} = RMS amplitude of the ripple voltage

V_{ave} = average DC voltages output

During charging by the alternator (106), the battery (110) converts the electrical energy to chemical energy in the battery cell plates. The main function of the battery (110) is to store electrical energy in chemical form when engine (105) is running, and to store the electrical energy for use to power starting, lighting, ignition ("SLI"), fuel pump, fan motor and other loads in the vehicle. The other function of the battery (110) is to act in the manner of a capacitor to smoothen the ripple generated by the alternator (101) and to provide a low impedance power source for improving the noise immunity created by the ignition circuitry and control unit.

The ripple voltage V_{rr} is determined as below:

$$V_{rr}=R_2*I_{rms}$$

where R_2 is the battery internal resistance

I_{rms} is the RMS value of charging current

The relationship of ripple factor R_f, ripple voltage V_{rr} and battery internal resistance R_2 is determined as below:

$$R_f=K_{r1}*V_{rr}=K_{r2}*R_2$$

where K_{r1} and K_{r2} are constants.

The equation shows that the ripple voltage is proportional to the battery internal resistance (R_2, 112) under the same charging current. Therefore, the ripple factor can be used to determine the performance of the battery (110).

The starting mechanism equivalent circuit

Figure 2 is a simplified engine starting mechanism equivalent circuit. The starter (101) consists of a resistance (103) (the total ohm value of the device), a series inductance (102), and a back emf (104) of the armature. The back-emf (104) is zero when the armature is at rest.

The battery (110) consists of an ideal voltage source (111) and an internal resistance (112). The terminal voltage V_t of the battery (110) is different from the ideal voltage source (111) due to voltage drop across the internal resistance (112) when the battery (110) is under load. Theoretically, the terminal voltage V_t is equal to the ideal voltage source V_o under a no load condition. This means that

$$V_t = V_o - I*R_2$$

where I = the load current

R_2= battery internal resistance

$V_t \equiv V_o$ when load Current $I=0$. And

$V_t \neq V_o$, or $V_t < V_o$ when $I \neq 0$.

If the load current $I_1 < I_2$, then the terminal voltage $V_1 > V_2$. The voltages V_1 and V_2 are measured with correspondence to the currents I_1 and I_2. This means that the higher the current load, the lower the terminal voltage output.

The cranking torque and cranking torque capability of the starter

Referring to Figure 2, at time t_1, under condition $0 < t_1 > \tau$ and the armature is at rest, the transient current I is simplified as follows:

$$I = V_o * t_1 / L \qquad (1)$$

where V_o = the ideal voltage of the battery

$\tau = L/(R_1+R_2)$ the time constant of the circuitry

L=the inductance of the starter

R_1=internal resistance of the starter

R_2=internal resistance of the battery

If $t_1 > \tau$, the current I is simplified as follows:

$$I = V_o/(R_1+R_2) \qquad (2)$$

Referring to equation (2), the current I is limited by the starter internal resistance R_1 (103) and battery internal resistance R_2 (112). The current I is directly proportional to the torque produced by the starter. The power output P_o of the battery before armature rotation can be determined as:

$$P_o=V_o*I - R_2*I^2 \qquad (3)$$

where $Vo*I$=total battery output power

R_2*I^2=the internal power lost of the battery

At maximum power transfer condition, $dP_o/dI = 0$.

The cranking current I is equal to the maximum power output cranking current I_n, then the maximum power terminal voltage V_n can be determined as:

$$I_n=K_n V_o/R_2$$

$$V_n=K_n *Vo \qquad (4)$$

where K_n is a constant

Normally, the maximum cranking current I_n must be greater than the require cranking current I_p. If I_R is the reserve cranking current, then the reserve cranking current I_R can be determined as:

$$I_R=I_n-I_p$$

When the battery is degrading, the stage will be reached where the maximum cranking current I_n is equal to or less than the required cranking current I_p. In this case the output current may not produce enough cranking torque to crank the engine.

The relationship between V_p, V_n, I_p and I_n is as follows:

$$V_p/V_n \mid I_p=I_n/I_p \mid V_n \qquad (5)$$

With reference to equation (5), V_p/V_n can be used to determine the degree of the vehicle cranking torque capability Q_t.

The cranking torque capability Q_t is as follows:

$$Q_t=I_n/I_p=K_p*V_p/V_n \qquad (6)$$

Where K_p is the conversion constant.

The gradient of cranking current before starter rotates

If v equals the induced emf of inductor L, the transient current i of the circuit can be determined as:

$$i=(V_o-v)/(R_1+R_2)$$

$$i=V_o/(R_1+R_2)-v/(R_1+R_2) \qquad (7)$$

The differential of equation (7) with variable i and v,

$$di/dt=-(dv/dt)/(R_1+R_2) \qquad (8)$$

The gradient of cranking voltage and cranking circuit quality

The cranking voltage gradient dv/dt, when the armature is not rotating, can be determined by multiplying L to each side of equation (8), then;

$$L*(di/dt)= -L*(dv/dt)/(R_1+R_2)$$

From Lenz's law, L*di/dt=V and V initially equal to V_o then

$$dv/dt=-V_o*(R_1+R_2)/L \qquad (9)$$

Referring to equation (9), the cranking voltage rate change (gradient) of dv/dt before the armature rotates is inversely proportional to the circuit resistance. If the battery terminal is poorly contacted, or the starter brushes are worn, the total circuit resistance will increase. Therefore, the resulting cranking voltage gradient dv/dt decreases. The change to the voltage gradient dv/dt can be used to determine the condition of to cranking circuit. If the parameters of the starter and the terminal connections have not changed, then the change to the cranking voltage gradient dv/dt can be used to determine the condition of the starter engine power system.

Using the same principle, the cranking terminal voltage V_t rate change is determine by using:

$$V_t=V_o-i*R_2 \text{ and } L*di/dt=V_o \qquad \text{then}$$

$$dV_t/dt=-V_o*R_2/L \qquad (9A)$$

Referring to equation (9A), the cranking terminal voltage gradient dV_t/dt before the armature rotates is inversely proportional to the battery internal resistance R_2. If the parameter of V_o and L do not change, the changes to the cranking voltage gradient dV_t/dt can be used to determine the condition of the battery.

If the cranking voltage gradient G_c=dv/dt, (or dV_t/dt) and the highest recorded cranking voltage gradient is G_{max}, then cranking circuit quality Q_c is determined as:

$$Q_c=(G_{max}/G_c) *100\% \qquad (10)$$

This means that if the elements in the circuit are working perfectly, the cranking circuit quality Q_c is equal to 1. If any one of the elements is degraded, the cranking circuit quality Q_c will be less than 1.

From equation (8) and (9) the cranking current gradient di/dt can be determined as follows:

$$di/dt=(V_o/L)$$

The gradient of the cranking current di/dt is directly proportional to the initial voltage V_o and inversely proportional to induction L of the circuit.

Maximum cranking power output and cranking power capability of starter and battery

Once the starter rotates, the armature generates back emf V_a.

The armature power output P_a is determined as follows:

$$P_a=V_a*I_a=V_o*I_a-(I_a^2*R_1+I_a^2*R_2) \qquad (11)$$

where I_a= the armature current

V_o*I_a=total power output from the battery

$I_a^2*R_1$=the copper lost of the starter

$I_a^2*R_2$=the internal power lost of the battery

V_a*I_a=armature electrical power equivalent to mechanical power output of the starter

The value of V_a*I_a is the cranking power of the starter (101). It is proportional to the mechanical output power of the starter. The product of armature output power ($P_a=V_a*I_a$) and duration T_d is the energy output of the starter (101). If the cranking power output of the starter (101) is a constant, then the longer the time required to crank, the more the energy required for the engine, and the poorer the cranking ability of the engine.

From equation 11, at maximum power transfer, if armature power output=P_m, armature emf = V_m, and $dP_m/dI_a=0$,

then,

$$V_o=K_1*I_a*(R_1+R_2)$$

and

$$V_m = I_a * (R_1 + R_2) = K_2 * V_o \qquad (12)$$

Where K_1 and K_2 are constants

From equation (12), under maximum power transfer, cranking armature voltage V_m is proportional to ideal voltage V_o.

If P_m is the maximum cranking power and P_a is the require cranking power, then the ratio of P_m/P_a is the degree of the cranking power capability Q_p of the vehicle starting mechanism.

$$Q_p = P_m/P_a \qquad (13)$$

The relationships between V_a/V_m and P_m/P_a are as follows:

$$P_m/P_a \mid V_m = f\ (V_a/V_m \mid P_a)$$

The cranking power capability Q_p can be determined as:

$$Q_p = P_m/P_a = f\ (V_a/V_m) \qquad (14)$$

To measure the armature voltage V_a is a difficult task. It requires the sensing of the armature voltage directly. This is impractical. However, converting the cranking terminal voltage V_{tc} to the armature voltage V_a equivalent is relatively easy. The relationship of V_a and V_{tc} can be determined as:

$$V_{tc} = K_a * V_a \qquad (15)$$

where K_a is the conversion constant.

V_{tc} is the cranking terminal voltage when armature rotating

Another method to determine the cranking power capability is to determine the ratio of cranking terminal voltage V_{tc} and maximum cranking power transfer terminal voltage V_{tm}.

From equation (12), under conditions of maximum power transfer, the battery internal resistance R_2 and starter internal resistance R_1 must be equal. The maximum cranking power output terminal voltage V_{tm} is as:

$$V_{tm} = K_m * V_m \qquad (16)$$

where K_m is the conversion constant

Normally, the cranking power of the starting mechanism is below the maximum power. This means that the maximum cranking power P_m must greater than the required cranking power P_a. The reserve power P_R can then be determined as:

$$P_R=P_m-P_a$$

When a battery is degrading, once the maximum cranking power P_m is equal to the cranking power P_a, then the reserve power $P_R=0$ this means the cranking operation is close to the maximum power. Any increase in the load of the engine (105) will cause the starter power output do drop thus causing cranking failure.

The ratio of V_{tc}/V_{tm} can be used to determine the degree of cranking power capability of the vehicle starting mechanism. The relationship between equation (15) and (16) is as:

$$V_a/V_m = K_t*V_{tc}/V_{tm} \qquad (17)$$

Where K_t is a constant factor, and

$$K_t=K_a/K_m$$

The cranking power capability Q_p is derived as follows:

$$Q_p=P_m/P_a$$
$$=f\ (V_a/V_m)$$
$$=f\ (K_t*V_{tc}/V_{tm}) \qquad (18)$$

where P_a is the cranking power output of the starter

P_m is the maximum cranking power output of the starter

Referring to Figure 1, the embodiment illustrated has a microprocessor (200), reference timer (204), memory (203), key-pad (205), input controller (300), power supply (303), voltage reference (304), voltage pre-scale network filter (305), temperature reference (306), engine speed sensor (307), waveform detector (308), output controller (400), output device display (501), full colour LED (502), speaker (503), infrared port (504) and computer link port (505).

The electrical power system (100) under test is connected to a high input impedance voltage pre-scale network filter (305). It is a low pass filter and a scaler to produce a correct voltage ratio, and to filter out high frequency noise before feeding the signal into the analogue-to-digital converter (ADC, 301), waveform detector (310) and voltage gradient detector (302).

The engine speed sensor (307) is used to detect the speed of the engine. It is optional for a gasoline engine but is required for a diesel engine as a diesel engine does not have an ignition pulse and thus the system cannot detect the engine speed.

The analog-to-digital converter (301) converts an analogue signal to a digital signal, and feeds the information to microprocessor (200) through the data-bus (208). The microprocessor (200) gates the ADC (301) under multiplexer mode.

Referring to Figure 4, the output controller (400) manages interface output from microprocessor (200) through the data bus (208). The digital-to-analogue converter (DAC, 401), has as its main function the conversion of digital signals to analogue signals. The character generator (402) generates messages according to test results with a data latch to drive the LCD display (501). The character generator (402) and the display (501) may be integrated and may be directly controlled by microprocessor (200) through the data bus (208).

The tone generator (403) generates sound tones or music according to test results and drives the speaker or speakers (502). Different tones may be used to identify different conditions of the vehicle electrical power system.

The colour pattern generator (404) generates different colour mixtures, light intensities, and on-off intervals to drive the colour LED (503). Different colour patterns may also be used to indicate the condition of the vehicle electrical power system.

The infrared printing interface (405) is an interface driver to drive the infrared transmitter (504) to provide a hard copy of a report on the condition of the vehicle electrical power system.

The computer interface driver (406) is connected to the port (505) to provide a data link with a computer to send reports on the condition of the vehicle electrical power system to the computer for storage and/or analysis.

The waveform detector (308) is a device to separate and detect the ignition impulse and the sinusoidal signal of the alternator ripple. Referring to Figure 2A, a signal waveform is obtained from the battery (110) terminals. It consists of impulse

signals A_1, A_2 generated by the ignition circuit, and a sinusoidal ripple signal generated by the alternator (106). The ignition pulse is narrow and sharp, and the period of A_1 and A_2 varies with engine speed. The ignition pulse frequency can be used to determine the engine speed S_e. If F_i is the ignition pulse frequency, and C is the number of cylinder of a four-stroke engine, the relationship is:

$S_e = K_e * F_i / C$,

where K_e is a constant.

For example, if C=4 and F_i is measured reading 33Hz, if K_e is 120, then the speed of the engine S_e can be determined as follow:

S_e =120*33/4=990 RPM

The ripple factor R_f can be determined as:

$$R_f = (V_{rr} / V_{ave})*100\% \quad (19)$$

Figure 2B is the ripple voltage waveform and Figure 2C is the engine ignition pulse waveform as separated by the waveform detector (308).

To detect a diesel engine running status, a speed sensor (307) is necessary. The engine speed detector is a magnetically coupled pulse generator, which generates a pulse waveform according to the crankshaft position and speed.

The waveform detector and engine speed sensor can provide the following information:

1) engine ignition pulse, or engine rotating pulse;
2) engine speed;
3) engine running status;
4) ripple voltage;
5) speed of the alternator; and
6) alternator working status.

Referring to Figure 3, the voltage gradient detector (VGD, 302) is a device that is highly sensitive to the voltage change gradient. It provides the gradient status and value when the battery (110) terminal voltage changes. The microprocessor (200) will combine, compute and analyse data from ADC (301), waveform detector (308), VGD (302) and speed sensor (307), and provide a control signal to the ADC (301) for data conversion.

The microprocessor (200) provides the following information:

1. voltage gradient (G) status of the terminal voltage ($G>0$, $G<0$ and $G=0$);
2. interval or duration (T_d) between two voltage gradient changes;
3. voltage change rate or gradient (dv/dt);
4. battery terminal voltage (V_t);
5. minimum terminal voltage (V_{min}) when the engine is running;
6. minimum terminal voltage (V'_{min}) when the engine is not running;
7. maximum terminal voltage (V_{max}) when the engine is running;
8. maximum terminal voltage (V'_{max}) when engine is not running;
9. average terminal voltage V_{ave};
10. amplitude of the ripple voltage V_{rr};
11. frequency of the ripple voltage F_r;
12. ripple factor of the ripple signal R_f;
13. regulator working status;
14. engine cranking status (this may include one or more of: starter engaged/disengaged, cranking, cranking passed/failed);
15. ignition pulse, or engine rotating pulse;
16. ignition pulse, or engine rotating pulse frequency F_i;
17. engine speed S_e;
18. engine running status $S_e=0$ or >0;
19. alternator speed S_a; and
20. alternator running status $S_a=0$ or >0.

Further more, the microprocessor (200) can automatically determine the condition and status of the electrical power system of the vehicle.

In the following gasoline system example, the judgement logic may be determined as follows:

Engine Status	Measurement Data
Ignition power on→off	
when $S_e=0$	$V_t \leq V_o$, and $G>0$ change to $G=0$
when $S_e>0$	$S_e>0$ change to $S_e=0$
Ignition power off→on	$V_{t1}<V_{t2}$ and $G<0$ change to $G=0$,
Cranking switch off→on	$G=0$ change to $G<0$

Cranking switch on→off	G=0 change to G>0
Cranking duration T_d	Time taken from crank starting to crank ending
Engine cranking failure	after cranking duration T_d, engine speed $S_e=0$
Engine cranking successful	after cranking duration T_d, engine speed $S_e>0$
Engine running	Ignition pulse>0 or Ripple>0 or $S_e>0$
Alternator malfunction	$S_e>0$ and ripple=0 or $S_e>0$ and $V_t<V_o$
Alternator partially function	$S_e>0$, ripple>0 and $V_t<V_o$ or $S_e>0$ and $R_f>5\%$
Charging system working	
Normal	$1.2\ V_o>V_t>V_o$ and $R_f<1\%$
Regulator out of order	
over voltage	$S_e>0$, and $V_t>1.2V_o$
under voltage	$S_e>0$, and $V_t<V_o$

The cranking torque capability Q_t and cranking circuit quality Q_c of the starter (101) and battery (110) circuit may also be determined. The cranking torque capability Q_t and cranking circuit quality Q_c are useful parameters for judging the static torque performance, and quality of the elements of the starting mechanism. The performance of the starting mechanism may be monitored, and defective elements in the system detected prior to failure.

Referring to Figure 8, there is shown a simplified functional flowchart (250) for determination of cranking torque capability and cranking circuit quality.

In step 252 the terminal voltage, and duration of the time during initial cranking (when the engine status "engine began cranking"), are detected and measured. The initial voltage V_t before cranking is recorded, as is the lowest terminal voltage V_p and the duration t_r before armature rotation.

The maximum power transfer current I_n is calculated (254) as is voltage V_n, based on the collected data V_o, V_t, V_p and t_r.

The voltage ratio of V_p/V_n is converted to the current ratio I_n/I_p (256) and the cranking voltage gradient G_c is determined as follows:

$$G_c=vd/dt =-(V_t-V_p)/t_r$$

where t_r = time taken from V_t to V_p.

The highest voltage gradient G_{max} will be recorded.

The cranking torque Q_t and cranking circuit quality Q_c is calculated (258) as follows:

$$Q_t=I_n/I_p =K_p*V_p/V_n$$

where K_p is a conversion constant.

$$Q_c= G_{max}/G_c *100\%$$

where G_{max} is the recorded highest value of G_c

This function also compares Q_t and Q_c with the acceptable values preset in the system to determine the acceptability of the measured values of the cranking circuit quality Q_c, cranking torque capability Q_t, condition of battery, starter, and connector. The determination will be used for final output later, preferably in the form of one or more of colour lights, musical tones, and messages. The results are recorded with a date-time log for future use. The future use may include functions such as event tracing, or auditing.

The cranking power capability Q_p of the electrical power system of the vehicle can also be determined. This includes the starter (101) that, together with battery (110), determines the cranking ability of the engine.

The cranking power capability Q_p is a useful parameter to determine the dynamic power output capability of the battery (110) and starter (101). It is a real time data measurement under actual operating conditions. It is an accurate determination of the cranking capability of the vehicle. An early warning of a low cranking capability of any component in the system can also be determined accurately.

Figure 9 is a simplified flowchart (260) for the determination of cranking capability.

The armature back emf V_a, terminal voltage V_{tc}, and duration T_d (time from when the armature begins rotating until the starter is disengaged from the engine) can be measured and recorded (262).

The maximum power transfer armature back emf V_m, maximum power transfer terminal voltage V_{tm}, the armature voltage ratio V_a/V_m and the terminal voltage ratio V_{tc}/V_{tm} are also calculated (264) and the armature voltage ratio V_a/V_m or terminal voltage ratio V_{tc}/V_{tm} is converted to the armature power ratio P_m/P_a (266). The cranking power capability Q_p can be derived as follows:

$$Q_p=P_m/P_a= f\ (V_a/V_m)$$

$$Q_p=P_m/P_a=f\ (K_t*V_{tc}/V_{tm})$$

where K_t is a constant.

The cranking power capability Q_p and the cranking duration T_d of the engine can be analysed (268). This is used to diagnose the cranking power capability of the starting mechanism, and the engine cranking ability respectively. Q_p and T_d are also compared with the acceptable values preset in the system to determine the acceptance of the measured values of cranking power capability Q_p and the engine cranking ability. The determination will be used for output later. This is preferably in the form of one or more of colour lights, musical tones and messages. The results are recorded with date-time log for future use. The future use may include functions such as event tracing or auditing.

Engine speed S_e, alternator speed S_a, terminal voltage V_t and ripple factor R_f may be used to determine and diagnose the working condition of an alternator, battery, and related components, such as, for example, drive belt, rectifier circuit and the regulator. Battery charging status, the deterioration of the battery, low electrolyte level, and insufficient alternator output power, can also be detected.

Referring to Figure 10, the flowchart 270 shows the process for determining the working condition of the alternator and battery with the engine running.

The engine speed S_e, the alternator speed S_a, the terminal voltage V_t, the maximum and minimum terminal voltage, V_{max} and V_{min}, are all measured respectively when engine is running (272).

The ripple voltage V_{rr}, the speed ratio of alternator and engine $N_a=S_a/S_e$, care calculated (274) and record the corresponding maximum speed ratio N_{max} recorded.

The average voltage V_{ave}, ripple factor R_f and the speed ratio change rate S_R are calculated (276) as follows:

$$R_f = (V_{rr} / V_{ave})*100\%$$

$$S_R=N_a/N_{max}$$

The speed ratio N_a is normally a constant, and $N_a=N_{max}$. If $N_a/N_{max}<1$, it shows that the alternator may have a fault. This may be, for example, when the alternator drive belt is loose and slippage results. In that case N_a will decrease. If one phase of the alternator is not functioning, N_a will decrease to one third of the normal value.

The ratio N_a/N_{max}, the terminal voltage V_t, the engine speed S_e and the ripple factor R_f are analysed (278) to determine the alternator and battery working conditions. N_a/N_{max}, R_f and V_t are compared with the acceptable values preset in the system to determine the acceptance of the measured values of speed ratio change rate N_a/N_{max}, ripple factor and terminal voltage. The determinations will be used for a final output in the form of one or more of colour lighting, musical tones and messages. The results are recorded with date-time log for future use, such as event tracing or auditing.

The discharge time remaining for the battery after an alternator breakdown, and during normal operation, can also be determined. By making use, of the engine running status, alternator working status, terminal voltage and voltage gradient it is possible to determine a remaining battery discharge time. It will be updated, and will self-correct, as a result of input of data relating to dynamic load changes and battery capacity changes. This may provide information to the user at fixed intervals on a continuous basis. Figure 11 (280) is a flowchart for determination of the remaining battery operating time.

The battery terminal voltage V_t, is measured and the engine running (S_e>0) status and alternator working status are determined (282). If the alternator (106) working status is abnormal, such S_a=0, ripple=0 or low voltage, the battery voltage V_t and the time t are recorded.

Terminal voltage change rate, Y, is detected and tracked (284) if the alternator is confirmed as operating abnormally. The battery discharge voltage gradient Y is calculated:

$$Y=(V_{t0}-V_{t1})/t$$

where V_{t0} is previous terminal voltage

V_{t1} is next terminal voltage

t= fixed time interval between data V_{t0} to V_{t1}

The remaining time, X, is calculated (286) based on the voltage discharge rate Y and the terminal voltage V_t. X can be determined as follows:

$X=(V_{t1}-\beta V_o)/Y$

where V_{t1} is the voltage corresponding to Y

βV_o is the end of discharge voltage (percentage of ideal voltage V_o)

β is expressed in percentage.

It is diagnosed at 288. It is refreshed at regular intervals such as for example, every 1, 10 or 120 seconds, due to dynamic load change. If the result is $X \leq 10$ minutes, the judgement of the engine status is that the engine may soon break down. The result may be output preferably in the form of one or more of colour lighting, musical tones and messages. The results are recorded with a date-time log for future use. The future use may include functions such as event tracing or auditing.

Referring to Figure. 4, the output controller (400) decodes the data from microprocessor (200) through databus (208) to control devices including a digital to analogue converter (DAC, 401), a character generator (402) to drive the LCD (501), a tone/music generator (403) to drive the speaker (502), an LED colour pattern generator (404) to drive the colour LED (503), an infrared printing interface (405) to drive the infrared transmitter (504), a computer link interface (406) with interface port (505).

The display may provide comprehensive information. Preferably the report cycle starts when the ignition is switched on, and reports continue at regular intervals until the ignition is switched off. The reports may be continuous.

There may be up to five modes of output:

1. <u>Message display</u>

Message displayed may include information on one or more of:
present battery terminal voltage;
initial battery voltage before load;

cranking circuit quality;
cranking torque capability;
cranking power capability;
minimum voltage at engine off;
maximum voltage at engine off;
minimum voltage at engine running;
maximum voltage at engine running;
ripple factor; and
battery remaining operating time when alternator failure;
and warnings of the battery terminal voltage is over or under the pre-set limits;
limited or poor cranking circuit quality;
limited or poor cranking torque capability;
limited or poor cranking power capability;
alternator malfunction;
alternator rectifier out of order;
remnant operating time of the battery if the engine running but the battery is not charging;
limited remnant time;
limited reserve cranking energy; and
alternator drive belt loose.

2. Visible colour pattern signal

The colour pattern generator (404) combines the colour, duration time and intensity of light to generate various colour patterns. Different colour patterns indicate different vehicle electrical power conditions and performances. The colour pattern generator (404) modulates a small number such as, for example, two or three primary colours. They are mixed proportionally to correspond to the battery (110) voltage. It therefore acts a colour-voltmeter.

For example, the colour-voltmeter may modulate the red and green LED illumination duty cycle according to the voltage range from V_1 to V_2. The colour may remain red if the voltage is less than V_1, and may remain green if the voltage is more than V_2. Where V_1 indicate weak battery and V_2 indicate serviceable battery.

The same concept may be used to modulate two or three primary colours (preferably different primary colours) to indicate the level of cranking torque capability and cranking power capability. These may be, for example, yellow and blue; orange and white; and so forth. Upon it being determined that the alternator and battery are in good condition, the LED may be reduced to an intensity as a percentage of full intensity, the percentage being in a range of 0% to 75%.

3. <u>Audible tone or musical signal</u>

The music tone generator (403) may generate different musical tones and/or tone intervals to indicate the condition of the vehicle electrical power circuit, especially under abnormal situations, to alert users. For example, a shrill, constant musical tone may indicate the system is abnormal, as in an alarm bell. A gentle musical tone or silence may indicate that the vehicle electrical system is normal.

4. <u>Infrared printing hard copy output</u>

The hard copy can be generated via infrared transmitter (405) to a printer for report with time/date logging, title of record, and detailed data for future auditing and use.

5. <u>Computer interface data output</u>

The detailed data generated by the system can also be transferred via a communication driver (406) and communication port (505) to a computer for continuous data storage, and data processing.

Whilst there has been described in the foregoing description a preferred embodiment of the present invention, it will be understood by those skilled in the technology that many variations or modifications in details of design, construction or operation may be made without departing from the present invention.